R&D Proposal for Detailed Simulations of Machine Background Sources and the Impact to Detector Operations

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Abstract

This proposal seeks funding to pursue research related to background sources in the experimental detectors due to operation of the eRHIC accelerator. Past experience at other facilities shows that synchrotron radiation and interactions of the beam with residual gas in the beamline are major sources of background which must be mitigated, although there are others which need investigation. Backgrounds such as these have an impact on the technologies that can be utilized for the main detector, as well as for the auxiliary detectors such as the luminosity monitor. Thus this study seeks to identify the dominant background sources, quantify the impact to the detectors and physics, and devise schemes to mitigate the backgrounds in the eRHIC designs. The studies are essential and should be developed in parallel to the interaction region design for the machine, as the backgrounds are dependent on the details of the machine lattice and beam optics. The knowledge obtained will help to guide the machine and detector designs in the best direction. This strategy has already proven to be effective for the eRD12 project, where cooperation between the experimental physicists and the machine design team has been crucial in guiding the IR design to be optimized for physics, while encouraging iteration and improvement in the design based on the impact to the relevant physics measurements.

1 Introduction

The design choices for the machine greatly impact background radiation that the detectors may see, which has significant impact to the physics program and the detector technologies that can be used, and can be a major source of systematic uncertainty. It is absolutely essential to have control of the systematic uncertainties at a future EIC, as the systematic uncertainties will dominate the high precision measurements from the high luminosity machine. This impact comes both from the physical arrangement of the magnet lattice that guides the beams, as well as the chosen bunch frequency, beam currents, and beam optics. The initial decisions regarding the layout of the Interaction Region (IR) and beam parameters (optics, bunching, etc.) are being made now, so it is crucial to have people who are both interested and possess expert knowledge in the experimental program collaborate with the members of the machine design group so that machine performance in terms of luminosity and acceptance can be optimally balanced for physics measurements and sources of background contamination from the machine. This document proposes, requests, and justifies allocation of funds to facilitate the study of these backgrounds in the current schemes for an eRHIC.

Further highlighting the importance of this study is the fact that BNL management has charged that two main accelerator options be developed. This includes the originally proposed linac-ring design, and a lower-risk ring-ring design which largely uses current available technologies, but may be upgradable to a linac-ring in the future. The proposed studies will be very important in helping to decide which layout to fully support in moving forward, as well as provides guidance to the machine developers on how each one will impact the physics. Thus it is imperative to have experimental physicists work closely with the machine designers in this regard, and additionally work with them during the design phase, so that changes can be made early on and propagated through the project. The proposed studies will also impact the detector planning, and will give a much better reference for the type of environment in which the detectors will need to operate.

We can draw on the extensive experience from previous experiments, thus it is important to discuss the shortfalls of the previous premier electron-proton collider of HERA at DESY. The EIC proposal is in many ways a natural extension and improvement of the previous HERA collider, where it is desired to push the limits in terms of luminosity for the next generation machine of EIC. It is documented [1, 4] that new challenges arose as HERA was upgraded from stage I to stage II. This was an upgrade to increase the luminosity of the machine (designed to be a factor of 7 increased, but achieved a factor of 5) by reducing the beam size at the Interaction Point (IP) and required some rearrangement of the interaction region layout. After recommissioning for the upgrade, very severe background conditions were observed, and the machine had to be shut down for several months while studies of the backgrounds were performed and solutions to mitigate the backgrounds were installed. The upgraded design suffered from large proton beam-gas interactions and increased synchrotron radiation. The problems were rectified during the shutdown, but this re-enforces the need for experts on the physics program at an EIC to work directly with the machine design group during the design phase, rather than after, and thus strengthens the case for funding for this study.

To summarize, the proposed study will focus on estimating machine generated backgrounds to the detectors, giving crucial information to all groups designing detector systems on the radiation environment in which the devices will operate. The study will additionally compare the two eRHIC design options of the ring-ring and linac-ring, to add support to which conception is the most promising in terms of physics measurements. The specifics of various backgrounds to be studied will be discussed in the next section.

2 Background Sources

Detailed simulation studies need to be performed for the relevant background sources. A subset of sources of background from other facilities are itemized below (though not always a clear separation of effects):

- Synchrotron radiation
- Beam-gas interactions
- Beam halo
- Beam losses
- Neutron flux
- Radiation from elastic scattering

Each bullet above will be discussed below, with relevant information on the background and how the background manifests in the detectors.

2.1 Synchrotron radiation

Synchrotron radiation can be a significant background to physics measurements, both in the main detector, as well as the auxiliary detector systems such as the luminosity monitor. The synchrotron radiation mainly originates from the electron beam bending through the magnets of the lattice. The current IR design already attempts to reduce the synchrotron radiation hitting the main detector by having a long straight section incoming into the IP.

Studies of how much synchrotron radiation is produced, as well as where the radiation hits are needed. For the IR, it is necessary to evaluate the expected synchrotron radiation that may hit the luminosity monitoring system. The current setup for the luminosity system is shown in figure 1. As is shown, the monitor is placed down stream of the IP and after a set of magnets that bend the electron beam away. Note this configuration is

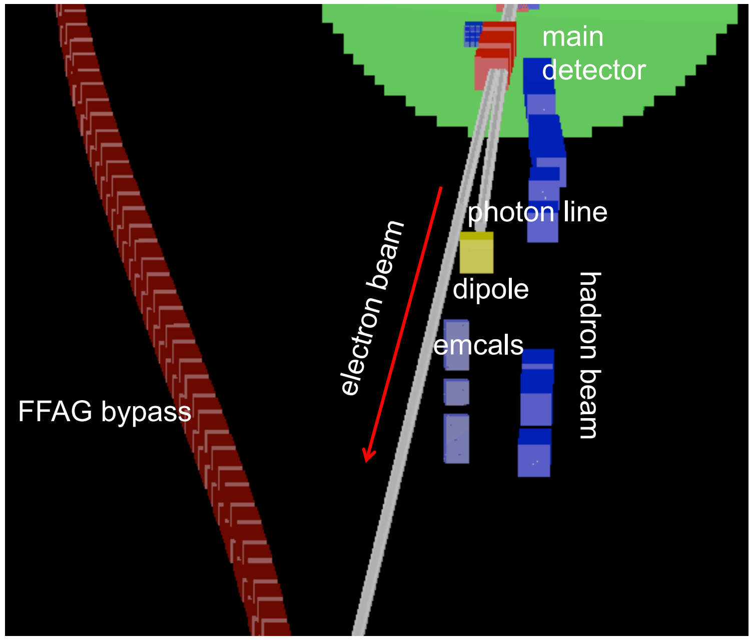

Figure 1: The current configuration of the luminosity monitor in the v2.1 linac-ring IR.

for the linac-ring v2.1 setup previously reported in [2]. The luminosity monitor must be designed so that it is sufficiently radiation hard so as to not get damaged, as well as having electronics that can handle the expected data rates. Most likely synchrotron radiation masks will be installed in front of the monitor, and the details of the mask is within the scope of this study. Quantitative estimates of the synchrotron radiation in the monitor is one of the proposed deliverables for this proposal and will impact the overall choice of detector technology to be used. Further, it needs to be studied where synchrotron radiation may be back-scattered into the main detector.

It is also necessary to study how much synchrotron radiation is expected in the region of the electron polarimetry system, which is another avenue this proposal seeks funding for investigation.

The amount of synchrotron radiation is dependent on the specifics of the machine. Since Brookhaven is developing two main machine options, it is very important to study synchrotron radiation backgrounds in each design. This will help to strengthen the case for one design over the other and will strongly influence the path forward. The experience and software developed by the current project members make them ideal candidates to carry out such studies.

To further strengthen the case for this study, let us again look to the example of the upgrade of HERA I to HERA II. The upgrade significantly increased the delivered luminosity of the machine, which increased the synchrotron radiation to due the stronger electron beam bending at the IP. One impact of this upgrade was the necessity to upgrade the luminosity monitoring system at ZEUS (by building a more radiation hard calorimeter, increasing the thickness of the synchrotron radiation filter, and installation of an electron-positron pair spectrometer). Another impact of the synchrotron radiation was vacuum leaks in certain locations of the magnet cryostats due to localized heating from synchrotron radiation of the flanges, causing them to pop. Again, this shows the need for these studies so that these types of issues can be planned for and avoided in advance of construction and operation.

2.1.1 Beam-gas interactions

Beam-gas interactions are essentially fixed-target p+A (and A+A when running ion beams) collisions and are a source of background events which must be rejected or otherwise accounted for. We again highlight the HERAII upgrade, where background from beam-gas interactions was the dominant source of background. In contrast to the eRHIC design, HERA had no crossing angle and thus had a long section of common beam-pipe. This increases the effects from beam-beam interactions and thus can be a source of increased radiation, as well as beam emittance growth. The effect was additional heating of the beampipe, which released residual gas from within the beampipe walls, effectively decreasing the vacuum and increasing the rate of beam-gas interactions very near the detector. One action taken to mitigate this specific issue was to run the machine with high proton beam currents to "bake-out" the gas in the beampipe walls. Additionally a procedure for regular warm-ups of the cold final focusing magnets in the interaction regions to room temperature to remove frozen gas significantly improved the observed dynamic vacuum.

The crossing angle at eRHIC will certainly help to reduce this type of effect, but quantitative estimates of the rates compared to rates of interesting physics processes is needed and falls under the scope of the proposed study.

2.2 Beam halo

Beam halo refers to the cloud of off-momentum particles that can travel with the main core of the beam. They arise from multiple processes such as beam-beam interactions and Bremsstrahlung. Apart from the impact of the halo to stability of the beam (which is a C-AD issue and will not be discussed further here), the halo also can be responsible for increased background rates in the detector due to these particles scraping the beam-pipe for example. This is also a background that needs to be studied in terms of what level detectors can reasonably tolerate.

2.3 Beam loss

Beam loss can cause significant damage to detector systems if proper controls are not put in place. Thus the detectors need to be protected from an unexpected beam loss (due to a magnet fire or other effects). This is another issue that needs study and can feed into the optimization of the placement of detector systems (and protections) in the IR.

2.4 Neutron flux

Low energy neutrons (with energies of a few hundred keV) can be very damaging to the detectors (silicon photo-multiplier sensors in particular). Quantitative estimates of the neutrons is essential in the planning of the detectors. A study done for STAR, with considerations for eRHIC, was done [3]. This study needs to be refined and repeated for the various IR configurations and part of this proposal seeks to extend this study.

2.5 Radiation from elastic scattering

Sometimes one person's signal is another person's background. This is the case with the elastic scattering of beam electrons and protons (or ions) at the IP. The so-called Bethe-Heitler process ($e + p \to e + p + \gamma$) will be used for the luminosity measurement [5, 6, 7], where we count the rate of photons from the process. Unfortunately the electrons from the scattering can be a background for physics measurements in other detectors (mainly the low Q^2-tagger [5, 6, 7]). Figure 2 shows that the energy range of electrons from the Bethe-Heitler process that hit the low Q^2-tagger. As can be seen, the electrons that hit the tagger are in a limited energy range (shown by the red line in the figure, compared to all electrons from the process in blue).

Since the elastic scattering has a relatively large cross-section compared to the interesting physics processes, this background will be large and a combination of event cuts and strategic detector placement will go a long way in reducing this background. This is another avenue for study within the scope of the proposal, building on the previous work from the eRD12 group.

3 Linac-Ring and Ring-Ring Designs and Their Backgrounds

There are two main machine design options being investigated at BNL, a Linac-Ring design and a Ring-Ring design. Each require their own IR layout and beam optics optimization. And each design will have different levels of machine backgrounds hitting the detectors.

Table 1 compares some of the relevant design parameters of the machine. The parameters are different, as thus result in different background rates and different actions to mitigate background sources. Experience from previous machines is important, but the eRHIC designs are quite unique and present their own challenges and thus these studies push the boundaries of the field.

One important distinction between the ring-ring and the linac-ring designs is that the ring-ring design needs more integrated beam current to reach the same luminosity of the baseline linac-ring design. This results in higher integrated synchrotron radiation rates

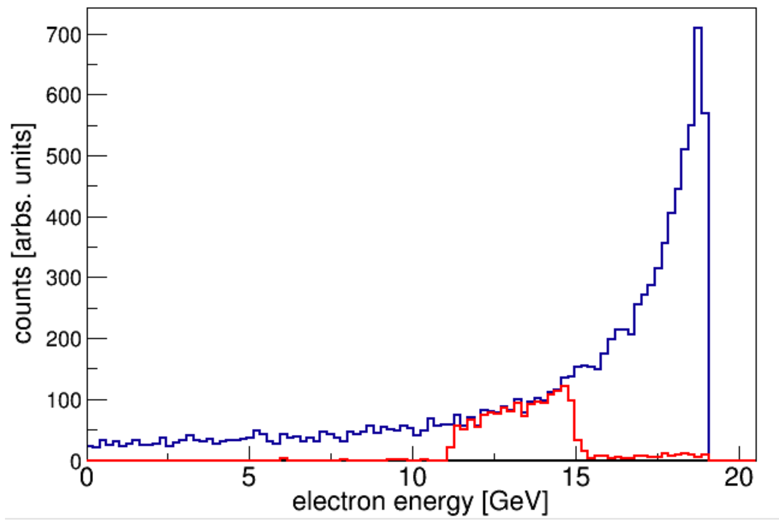

Figure 2: The energy range of background electrons that hit the low Q^2-tagger from the Bethe-Heitler process at with 20 GeV electrons colliding with 250 GeV protons (shown in red) compared to all primary electrons emitted from the process (blue).

Parameter	Linac-Ring (v2.1)	Ring-Ring (baseline)	Ring-Ring (upgrade)
COM energy GeV	141.4	141.4	141.4
Luminosity $10^{33}\text{cm}^{-2}\text{s}^{-1}$	4.1	1.06	3.0
Number of bunches	120	360	5591
Electron			
Bunch population 10^{11}	0.07	1.14	0.07
Beam current A	0.010	0.508	0.50
Total SR power MW	< 3	23.9	23.6
IP betas x, y m	0.050,0.050	0.38,0.27	0.023,0.032
Bunch length m	0.004	0.012	0.012
Proton			
Bunch population 10^{11}	3.0	3.0	0.2
N. emit μm	0.2	2.5	0.34
IP betas, x, y m	0.050,0.050	2.16,0.27	0.198,0.049
Bunch length m	0.05	0.2	0.035

Table 1: The comparison of some machine and beam parameters for electron and proton beams at the top ring energy of 20 GeV electrons and 250 GeV protons.

Event Type	Linac-Ring	Ring-Ring
Deep Inelastic Scattering	40.6	2815
Bremsstrahlung	1	3.6
Beam gas (proton beam)	177	2657

Table 2: The average number of bunch crossings in the interval between events of different types. Deep inelastic scattering (good physics) events occur at approximately the same rate as beam-gas events.

in the ring-ring design as opposed to the linac-ring. This information is critical in the general detector design. The repetition rate for the bunches in the ring-ring design is also larger than for the linac-ring design and can have an influence on the backgrounds that the detector sees.

Initial calculations for beam-gas event rates compared to the rate of true e+p and e+Au events are shown in Table 2, tabulated for the linac-ring and the ring-ring options. Though an accurate estimate is still needed, which depends on the detailed pressure distribution in and around the IR, initial estimations shows there does tend to be a high acceptance from events at a significant distance upstream of the detector.

Several assumptions have gone into the calculation summarized in the table as follows:

- Vacuum pressure of 10^{-9} mbar, which is similar to the vacuum pressure at HERA and the LHC
- The beampipe is at room temperature. This is a bad assumption near the cold superconducting IR magnets, and the beam-gas event rate increases with decreasing beampipe temperature, but depends on details such as possible heating from sychrotron radiation.
- The atomic weight for the beam gas is $\langle A \rangle = 40$.
- The beampipe is 10 m long, for a density of 2.65×10^{10} molecules/cm^2.
- The luminosity in the linac-ring design is $4.1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, with a proton bunch population of 3×10^{11} and a bunch spacing of 100 ns.
- The luminosity in the ring-ring design is $3.0 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, for 5591 bunches, with a bunch spacing of 2 ns and a proton bunch population of 2×10^{10}.
- 20 GeV electrons collide with 250GeV protons.

The study also proposes to investigate the dependence of the backgrounds on the collision energy, extending the initial calculation presented here.

4 Project Deliverables

There are several project deliverables the study will achieve. These are itemized below:

- Run existing packages and/or develop code to model synchrotron radiation to determine where radiation goes, where masks are needed, provide recommendations and guidance for new machine lattice layouts. Drawing from the experience (simulation code) of NSLSII at BNL may be possible here.
- Use simulation to quantify and track synchrotron background in detectors and determine major design impacts that need attention.
- Determine how the synchrotron radiation background compares to the rate of physics interactions (study signal to background).
- Run existing package and/or develop code to model beam-gas interactions.
- Use simulation to quantify and track background from beam-gas interactions and determine the impact to the physics measurements.
- Quantify the levels of neutron flux to the experimental area.
- Further optimize placement of auxiliary detectors (such as the low Q^2-tagger) for reducing background.
- Provide feedback to the machine design group in an iterative design process and help guide the design optimized for physics.
- Overall, quantify background radiation and event levels hitting the detectors in current IR designs to help guide detector technology design choices and optimization of placement.

5 Funding Requests

The requested funds and associated allocation is summarized in Table 3, with the bulk of the funds going to fund a post-doc salary.

	FY 2017
Cost for PostDoc salary fully burdened	100,000 (9 months)
Cost for travel to invite experts and to go to relevant conferences	10,000

Table 3: Cost breakdown for requested funding.

Additionally, the available manpower and contributors to the project are listed below. Work split/assignments:

- IR design: Brett Parker, Dejan Trbojevic, Christoph Montag, Robert Palmer and the eRHIC machine design team.
- Overall Detector and IR MC framework: A. Kiselev, R. Petti.
- Simulation for backgrounds: E.C. Aschenauer, R.Petti.

References

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